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Influence of fatigue crack on strength reduction of jacket brace members under ship impact

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ABSTRACT: Most tubular joints in fixed offshore platform are subjected to cyclic loading. Because joints have limit displacement, time developing loads cause fatigue damage. Therefore local strength of joints decreased and even in high failure scenario separation of member form the joint may occurs. On the other hand, considering ship impact on structure, plastic deformations may be observed in the jacket braces; however, members after collision must be maintained in safe and no fracture is occurred. The kinetic energy is absorbed by global platform displacement, dent formation, deformation of brace due to bending and strain energy due to axial tension forces. In this study, both effects of fatigue crack and ship impact on structure are investigated. The non-linear elasto-plastic collapse analysis is performed for jacket structure under ship impact for intact and cracked brace members at their connection. Results from comparison show that smaller cracks play unimportant rule on member failure but bigger cracks have more effects than smaller crack on brace intersection for reduction of absorbed ship kinetic energy on brace and should be taken in account during reliability analysis.

KEY WORDS: fatigue crack, ship impact, collapse analysis, strength reduction of brace

INTRODUCTION

Offshore platforms are memorable structures for exploration of oil and gas resources from the ocean beds, so investigation of performance conditions of platforms during lifetime is an essential aspect. Offshore zone can experience severe conditions which caused various damages due to fatigue phenomena and vessel impact defect. Ultimate capacity of a structure depends not only on design conservation but also on system effects beyond the first member failure (Karamchandani & Cornell. 1991).

Accidental loads from ship and vessel impact during approaching to platform criticize induced load pattern on structure. Lateral ship impact, causing the kind of imperfection to which the axial strength of tubes is highly sensitive, has a detrimental effect on the performance of tubular joint (Zeinoddini *et al*. 1998). In other words, after each impact on structure members, an undesirable effect has been remained such as local denting and cracking. Due to the stochastic nature of wave motion, often fatigue cracks are initiated at joints of elements and repetition of such harmonic forces resulting in crack growth. Splash zone on jacket structure is more capable for generating such these cracks. If cracks or denting are generated at joints, strength reduction of member is occurred and during sequenced impact loads in storm condition, failure of member is resulted and eventually cause to jacket collapse.

Some damages mentioned in pervious section may lead to the failures of platforms with severe consequences. The Health and Safety Executive, UK, 1994 has listed some main causes of structural damage for installation in the North Sea as shown in Table 1.

Table 1 main causes of structural damage

Damage Source	Fatigue	Vessel impact	Dropped objects	corrosion
Percent	25	24	9	6

Table 1 reveals that fatigue and vessel impact are principal factors of damage in offshore structure and influence of these two factors on fixed platform can affect overall stability and causing failure. To effectively repair the damaged members and restore the desired state of the structure requires a good assessment of the condition of the structural system after an accidental event (Jin *et al*. 2005).

Reliability of offshore platforms, especially jacket type is more and more used in requalification studies. A global failure mode is the result of the combination of local failure modes of some components of the structure: member, joints, foundations, etc (Morin *et al*. 1998). Therefore, failure of one or more members in jacket structure can lead to global structure failure. So investigation about local member deterioration under accidental load is necessary.

JACKET MODEL SPECIFICATION

One of South Pars jacket platform in Persian Gulf is used for assessing impact effect on structure that is shown at Figure 1.

Configuration of model is as follows:

Water depth at jacket position is 61.60 m below LAT (lowest Astronomical Tide). Four legged jacket with four main piles to support wellhead production facilities is considered as model geometry. Leg batter in Row 2 is single batter at 1:7 slope and in Row 1 are double batters at 1:8 and 1:7. Leg Spacing at working point is 20m ×

13.716m. Foundation has four driven piles grouted to jacket legs.
Barge bumpers on four jacket legs and boat landing on Row A are considered as Appurtenances.
Jacket framing elevations are pursued as below:
Sea deck Walkway: Elevation +6.7 m
Pile cut-off: EL. +7.900 m
Top of jacket: EL. +7.250 m
Work Point: EL. +8.300 m
Level-1 (Sea deck): EL. +5.750 m
Level-2: EL. -15.000 m
Level-3: EL. -38.000 m
Level-4: EL. -61.600 m

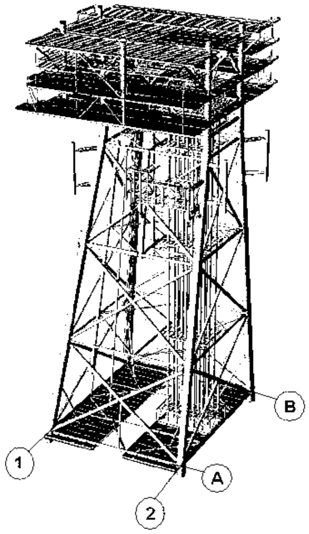

Fig. 1 Wellhead Platform Jacket General Arrangement

Number of joints, beams and plates are 3037, 5348 and 198 as defined as model parameters. Design check of platform is accordance with API, (2000).

IMPACT ANALYSIS

This section reports the analysis of an accidental boat impact on the wellhead platform. The objectives of the accidental impact study are to demonstrate:
- The jacket members can absorb the impact energy from a 1500 MT boat colliding with the jacket and hence stop the boat from going underneath the deck and impacting the conductors and risers.
- No rupture in the braces, but plasticity and hinges may form.

The non-linear analysis of the boat impact on brace jacket members in the impact zone performed using SACS finite element program.

DESIGN CRITERIA

The design impact kinetic energy is calculated from Eq. 1 for broadside collisions and bow/stern collisions:

$$E = \frac{1}{2} aMV^2 = 0.263 \text{ (broadside collisions)} \qquad (1)$$
$$= 0.206 \text{ MJ (bow/stern collisions)}$$

Where a is added mass coefficient that is considered 1.4 for broadside collisions and 1.1 for bow or stern collisions, V is vessel velocity with minimum of 0.50 m/sec and M is vessel mass 1500 MT (Length = 55 m, Width = 12.2 m).
The design impact is to be absorbed 100% by the jacket structure. Impact load were applied to first elevation of brace intersection that is shown in Figure 2. Plastic deformation is allowed under the design criteria but formation of collapse system mechanism shall be prevented. A one third increase in basic allowable stresses is considered for the jacket brace members.

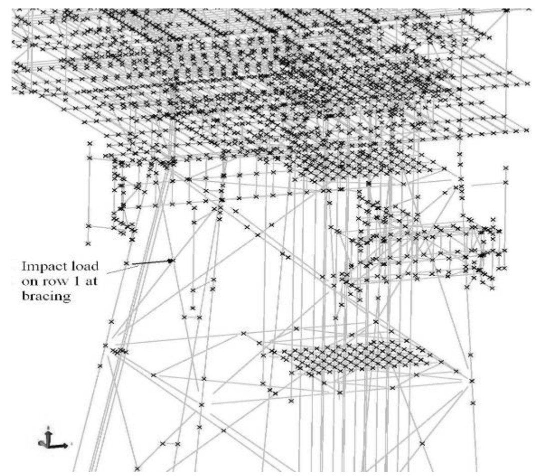

Fig. 2 Impact load location on jacket

In the initial stages of brace deformation subjected to vessel impact, the response is governed by bending effects which are affected by local denting and buckling, under the load. As the brace member undergoes finite deflections, the load carrying capacity may increase due to the development of axial tension forces. Provided that the structure does not fail, the energy absorption capacity is restricted either by excessive straining of the brace tube or joint failure. The kinetic energy is absorbed by global platform displacement, dent formation, deformation of brace due to bending and strain energy due to axial tension forces. For collapse analysis maximum deflection allowed before collapse is set 500 cm. Deflection and rotation tolerance for convergence are 0.1 cm and 0.001 rad. Finally strain hardening ratio is 0.005.

The following assumptions are used in the non-linear boat impact analysis:

1. The allowable stress for design of joints and members shall be the material yield strength.

2. Idealized elasto-plastic stress-strain curve was assumed for the steel material in the analysis. No strain hardening has been considered. Figure 3 presents a typical idealized stress-strain curve for structural steel.
3. The structure was analyzed to ductile failure. All of the impacted tubular members are subjected to member fracture control. The ductility limit is monitored by material strain, which is restricted to a value of 0.15 (15%), ensuring no rupture/fracture of material due to large plastic tension strain.
4. The design accounts for energy absorption of the structure by member local denting, member deformation, and jacket global deflection. Energy absorption arising from denting of the vessel was not considered.

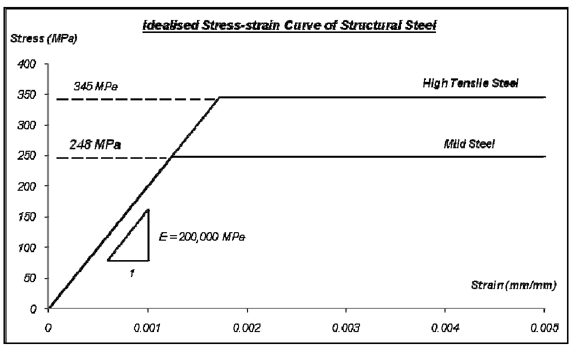

Fig. 3 Idealized stress-strain curve for structural steel

FATIGUE CRACKS

Most tubular structures are always subjected under severe cyclic loading conditions in practice, and fatigue cracks may develop resulting in fatigue damage (Chiew *et al.* 2004). If fatigue cracks do not detect, crack growth at joint cause member cut from intersection. For present study, cracks are defined as member section reduction to four different positions. Different crack states are shown in figure 3 as crack angle for 22.5º, 45º, 90º and 180 º or equal to 6.25%, 12.5%, 25% and 50% of circular perimeter length of tubular joints.

Moment of inertia of each crack cases for moment of inertia about local Y axis (M_{yy}) and moment of inertia Non-linear collapse analyses run for intact and with different cracks states. Elastic and plastic utilizations can be calculated from equations 2, 3 and 4 respectively. Reduced areas of each cracked sections also are calculated. Moment of inertia of each tubular section also verified via model program.

$$I_{yy} = \int zdA \tag{2}$$

$$I_{zz} = \int zdA \tag{3}$$

$$Jo = I_{yy} + I_{zz} \tag{4}$$

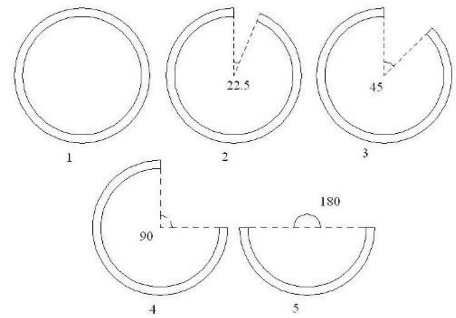

Fig. 4 Different cracks on member section

RESULTS AND DISSCUSION

After applying the weak section member properties in model, collapse non-linear analysis on jacket platform for progressive load impact on brace is performed. Load steps start with 200KN and continue until failure. Local elastic and plastic ranges are shown in Figure 4, 5 for intact and 50% crack respectively. Although displacement of brace intersection under progressive load goes up but the computed results also show that the total displacement of the overall jacket structure under the impact loading is small that confirm by Jin *et al*, 2005**.** Plastic deformations were observed in the jacket braces during impact, however no member fracture is observed for intact, 6.25% and 12.5% crack but for cracks with more than 25% member failure happen.

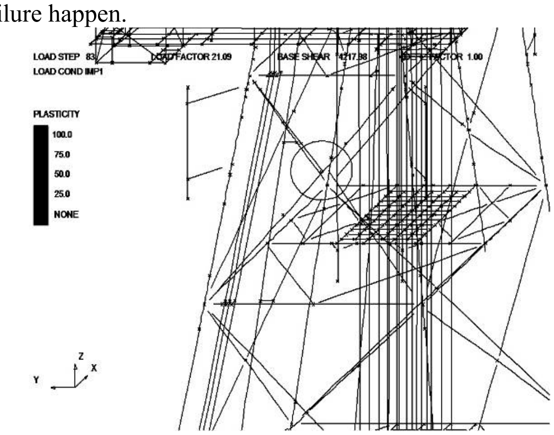

Fig. 4 Elastic and plastic utilization for intact case

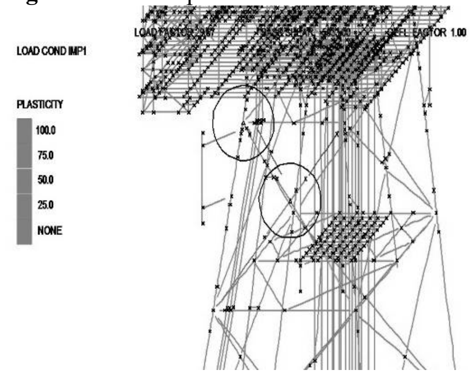

Fig. 5 Elastic and plastic utilization for 50% crack

Force-deflection curve for intact and crack sections cases are given in figure 6 together. Beneath the force-deflection curve introduce total absorbed energy by brace members. If total absorbed energy from impacted brace before failure is higher than 0.263MJ, this member has capability to withstand under ship impact load, else brace member has failed during impact because its energy to absorb impact load is not sufficient.

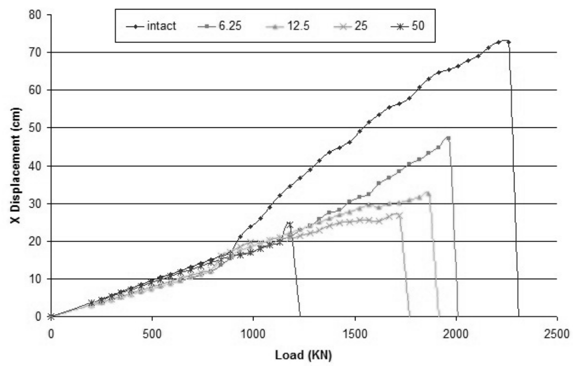

Fig. 6 Load-Displacement curve for different cases

Table 2 introduces failure load steps and total absorbed energy compare to intact section case that is occurred for different states.

Table 2 Failure comparison for five distinctive sections

Crack Condition	Maximum load (KN)	Energy (MJ)	Decreased Energy %
Intact	2258	0.7546	0
6.25% crack	1964	0.3756	50.22
12.5% crack	1866	0.3088	59.08
25% crack	1718	0.2520	66.60
50% crack	1180	0.1252	83.41

This table shows brace intersection joint can experience large deflection to absorb ship energy for intact, 6.25, 12.5% crack, but due to enhance fatigue crack length, maximum energy absorption until failure is lessened and collapse of brace happens. Table information exhibits that with crack increment, failure condition criticizes and this relationship is not linear. In fact with existence of cracks in member, load carrying capacity is decreased and load impacts on members with cracks are more dangerous with 25% of cracks on members. Also overall pattern of elastic and plastic utilizations are become different with intact case and plastic utilization.

CONCLUSIONS

From this study on jacket brace strength under ship impact and comparison between results of intact case and crack member section, following outcome are extracted:

1. Ship impact on brace member at highest level of brace location in platform can threaten the overall stability of brace member. Fatigue cracks at brace intersection decrease the amount of absorbed energy of brace member during impact load. This defect is considerable for cracks with length of more than quarter of circular parameter tubular joint.
2. Decreased energies for 6.25% and 12.5%, 25%, 50% of crack lengths are 50.22%, 59.08%, 66.60% and 83.41% of intact load impact.
3. Elastic, plastic utilisation in jacket brace member row are different cracked cases and creation of plastic joint is happen rapidly than intact case.

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